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Retrieval of water vapor using SSM/I and its relation with the onset of monsoon

R. P. Singh^{1,2}, S. Dey¹, A. K. Sahoo², and M. Kafatos²

¹Department of Civil Engineering, Indian Institute of Technology Kanpur-208016, India

²School of Computational Sciences, George Mason University, Fairfax, Virginia 22030, USA

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Abstract. The seasonal variations and interannual variability of total precipitable water (TPW) deduced from the Special Sensor Microwave Imager (SSM/I) satellite over oceanic regions of the Indian sub-continent during the years between 1988 to 1998 show characteristic behavior. The weekly patterns of TPW are found to be closely related to the dynamics of the climatic conditions and the onset date of monsoon. The present results show that the satellite monitoring of TPW may prove as a good and reliable indicator in forecasting Indian monsoon.

Key words. Meteorology and atmospheric dynamics (climatology; tropical meteorology) – Oceanography; general (ocean prediction)

1 Introduction

Water vapor plays a major role in the dynamics of atmospheric circulation, as well as in radiation exchange with the atmosphere (Ross and Elliott, 1996). The knowledge of total water vapor has paramount importance to the understanding of monsoon behavior, which, in turn, helps in weather forecasting. Numerous scientists have successfully deduced the surface temperature over land and ocean (McFarland et al., 1990), TPW over ocean surface (Alishouse et al., 1990), rainfall and clouds over oceanic region (Ferraro et al., 1996; Prabhakar et al., 1982; Stephens, 1990; Weng and Grody, 1994) and atmospheric water vapor over ocean (Schluessel and Emery, 1990) using passive microwave remote sensing data. Singh et al. (2000) have analyzed the monthly and seasonal TPW over the Arabian Sea and the Bay of Bengal, and have found a close relationship with monsoon. Simon and Joshi (1994) have studied the changes in TPW from NOAA/TOVS over various regions of the Indian Ocean, the Bay of Bengal and the Arabian Sea. Recently, Simon et al. (2001) have found a sharp increase in water vapor three

weeks before the onset of monsoon, based on Multi-scanner Microwave Radiometer (MSMR) data for a limited period of April–June 2000.

In the present paper, weekly and monthly averaged TPW over the Indian oceanic region (0–15° N, 60–80° E) for the years between 1988 to 1998 have been analyzed during May and June to examine the behavior of TPW over the Arabian Sea and the Indian Ocean around the monsoon onset period. The monthly averaged latitudinal variations of TPW have been compared with the sea surface temperature (SST) during 1994 to 1998. The onset dates of monsoon during 1988–1998 show a characteristic behavior, showing maxima TPW near the southern Indian coast (10–15° N) where the monsoon hits first. Efforts have been made further to find a close relation to the daily TPW with the onset dates of monsoon. Due to poor temporal resolution of SSM/I data, the present study is based on six days of averaged TPW, which show a maxima peak of TPW about 8–9 days prior to the onset day of monsoon.

2 SSM/I Data

SSM/I is flown on the Defense Meteorological Satellite Program (DMSP) Block 5D-2F8 spacecraft in a circular Sun-synchronous near-polar orbit at an altitude of 833 km with an inclination of 98.8° and an orbit period of 102.0 min. The orbit produces 14.1-full orbit rotation per day, and has a 06:13 a.m. local ascending node equatorial crossing. The SSM/I is a seven-channel, four-frequency, linearly polarized, passive microwave radiometric system. It receives vertically and horizontally linearly polarized radiations at 19.35, 37.0 and 85.5 GHz and only vertically polarized radiation at 22.235 GHz. The sensor samples every 12.5 km along-track at 85.5 GHz and every 25.0 km in all other frequencies (Hollinger, 1991). SSM/I covers the whole globe in two days with some gaps in data. The NOAA/NASA Pathfinder Programme EASE-Grid brightness temperature data have been obtained from the National Snow and Ice Data Center,

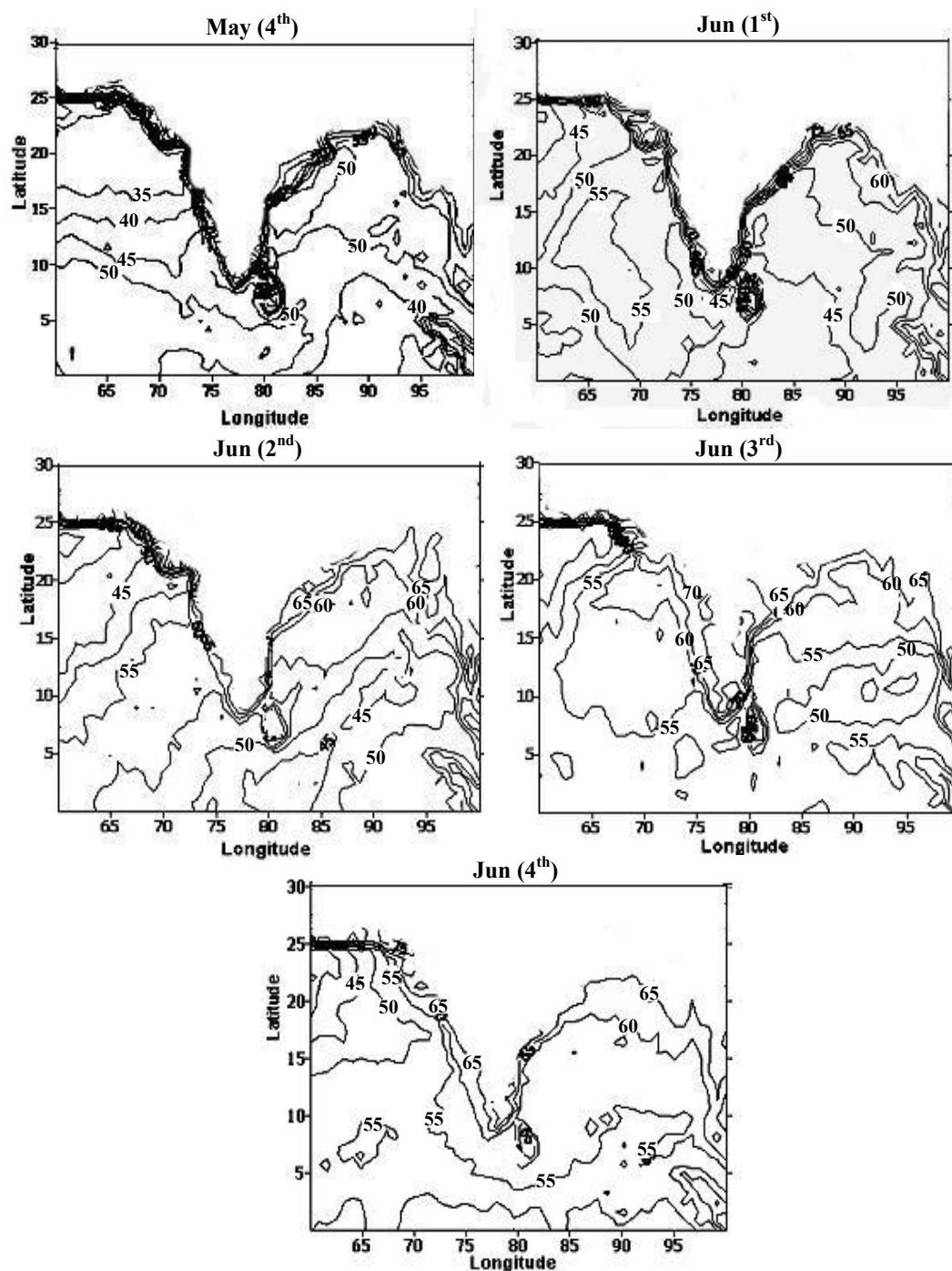


Fig. 1. Weekly variations of TPW (kg/m^2) prior and after onset of monsoon during 1997 (June 2nd week figure corresponds to the monsoon onset week).

Table 1. Monsoon onset day during 1988 to 1998 (from Indian Meteorological Department, Pune).

Year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Onset date of Monsoon	26 May	3 June	19 May	2 June	5 June	27 May	28 May	8 June	3 June	9 June	2 June

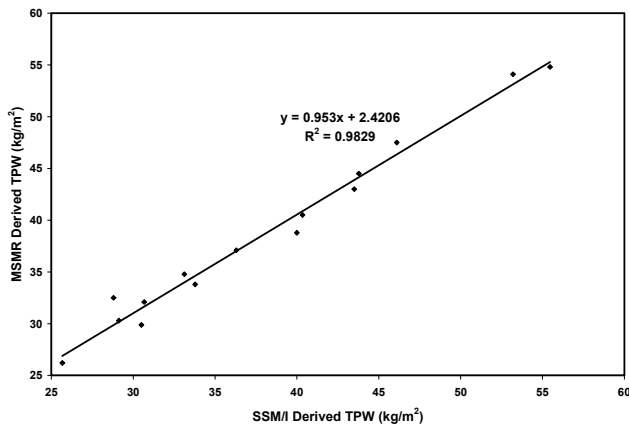


Fig. 2. Scatter Plot between SSM/I derived TPW and MSMR derived TPW for June 2000.

Boulder, Colorado, USA. The weekly and monthly averaged TPW (kg/m^2) over the Indian sub-continent have been calculated using the following algorithm (Alishouse et al., 1990):

$$\text{TPW} = 232.89 - 0.1486(T_{B19V}) - 0.3695(T_{B37V}) \\ [-1.8291 - 0.006193(T_{B22V})](T_{B22V}), \quad (1)$$

where T_{B19V} , T_{B37V} and T_{B22V} are brightness temperatures at 19.35, 37 and 22.235 GHz in vertical polarization, respectively.

The TPW retrieved from SSM/I has been compared with the TPW retrieved from IRS P4 multifrequency scanning microwave radiometer (MSMR) data of the same region using the algorithm given in Eq. (1). IRS P4 MSMR sensors on-board IRS-P4 (Oceansat - 1) which was launched by the Indian Space Research Organisation on 26 May 1998. The MSMR provided global microwave brightness temperature measurements at 6.6, 10.65, 18.0 and 21.0 GHz frequencies with vertical and horizontal polarizations. For TPW calculation using MSMR data, algorithm (Eq. 1) developed by Alishouse et al. (1990) was used with the brightness temperature 18 and 21 GHz vertical polarization instead of 19 and 22 GHz.

3 Results and discussion

Using Eq. 1, weekly averaged TPW have been computed to examine the behavior of TPW in the week of the onset of monsoon at the Kerala coast. Weekly variations of TPW over the adjacent oceanic regions bounded by 60 to 100° E longitude and 0 to 25° N latitude have been analyzed two weeks prior and two weeks after the monsoon onset. The behavior of TPW for the onset week of monsoon and two weeks prior and after the onset week are found to be very similar, with little change between 1988–1998. In Fig. 1, an example of TPW behavior for two weeks prior and two weeks after the onset week of monsoon has been shown for the year 1997. The TPW over the Arabian Sea changes significantly

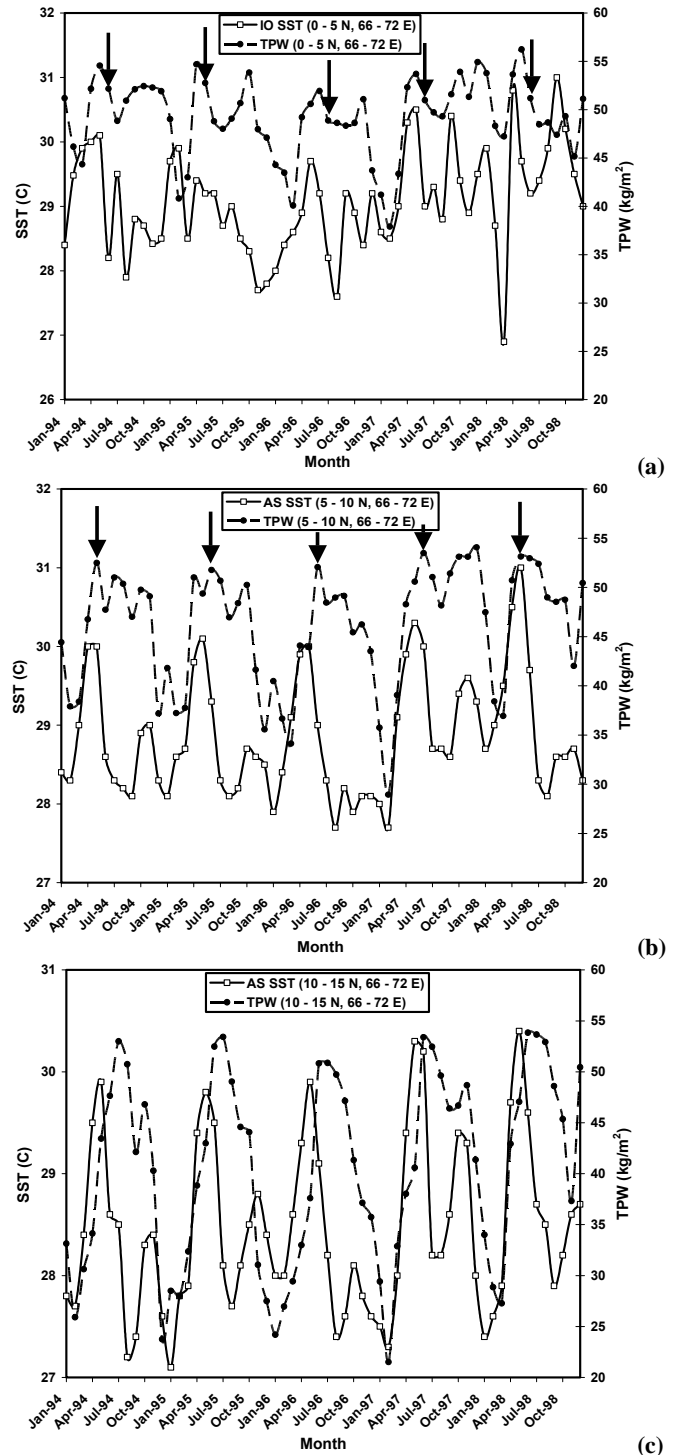


Fig. 3. Monthly variations of TPW with SST during 1994 to 1998 in (a) 0–50° N, (b) 5–10° N and (c) 10–15° N.

(see the contour values of TPW) before and after the monsoon onset. During the onset of monsoon in the year 1997 (2nd week of June, Table 1), the maximum TPW value of 55 kg/m^2 is found over the Arabian Sea coast. The maximum value of TPW persisted for about a week after the onset of monsoon in the second week, and afterwards the TPW

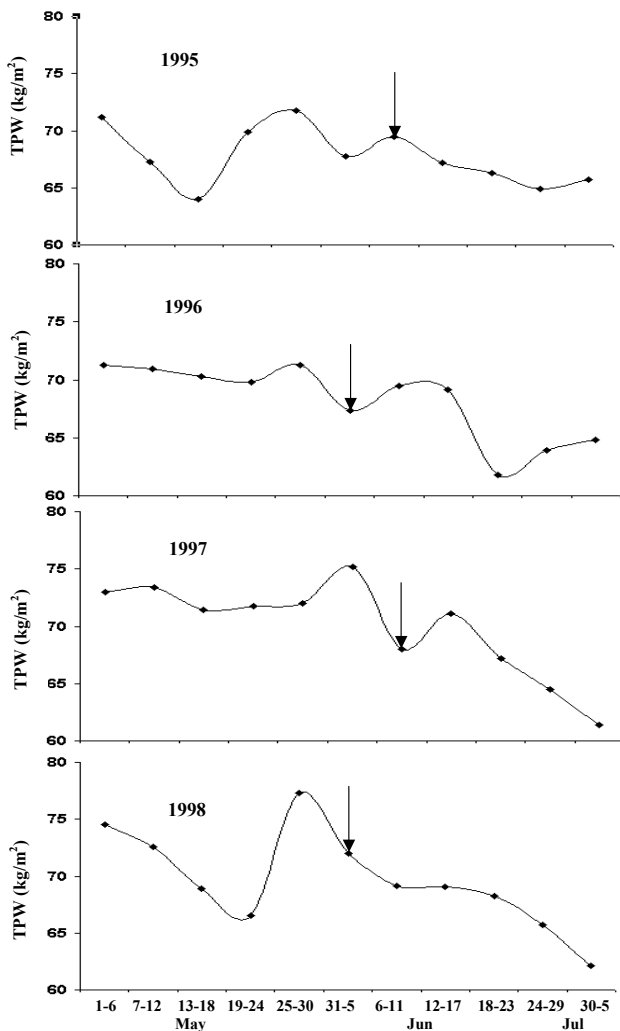


Fig. 4. Weekly variations of TPW in the latitude zone 10–15° N for 1995–1998.

value decreased during the 4th week. Such type of systematic behavior has been observed during 1988 to 1998, but the results are shown here for the year 1997 only. It is difficult to validate the TPW deduced from satellite data especially over the ocean, however, we have shown the correlation between TPW obtained from SSM/I and MSMR (IRS-P4 Oceansat) sensors. We have compared the TPW retrieved from SSM/I with the TPW retrieved from MSMR for the same region. Here, one may note that the SSM/I data was available in the grid resolution of 25 km×25 km and MSMR data was available in the grid of 50 km×50 km, the brightness temperature data were extracted for same bounded region and averaged for the month of June 2000 for comparison. The comparison of TPW retrieved from SSM/I and MSMR (Fig. 2) shows a very high correlation ($R^2=0.98$). The details of the comparison of SSM/I and MSMR data has also been discussed recently by Varma et al. (2002).

Figure 3 shows the variations of TPW and SST over the Indian Ocean and the Arabian Sea during 1994 to 1998 for

0–5° N (Fig. 3a), 5–10° N (Fig. 3b) and 10–15° N (Fig. 3c) latitude and 66–72° longitude zones. The arrows show the onset month of the monsoon over the Kerala coast of India. For latitudinal zone 0–5° N, no correlation of TPW and SST has been observed (Fig. 3a), whereas for other latitude zones, higher correlation of TPW and SST (of the Indian Ocean and the Arabian Sea) are clearly seen (Figs. 3b and c). The maximum value of SST ($\sim 30^\circ\text{C}$ or more) in the 5–15° N latitude zone is found one month prior to the maximum value of TPW or the onset of monsoon. The maxima of TPW shows a close relationship with the onset date of monsoon, which also has a close relationship with the SST of the Indian Ocean (IO_SST). The close correlation shows that the monitoring of SST may give early information about the onset of monsoon one month prior to the TPW. The trend of increase of TPW to maximum after an increase in IO_SST and SST of the Arabian Sea (AS_SST) in the 5–15° N latitude zone indicates the onset month of monsoon at the Kerala coast.

In order to examine a close relationship with TPW and the onset day of monsoon, six days averaged TPW have been computed. Due to poor daily temporal coverage, six days of averaged TPW has been considered for better accuracy and better temporal coverage, although the SSM/I sensor covers the whole globe in two days with few areas missing in data due to various limitations. Figure 4 shows the variations of six days of averaged TPW over the latitude region 10–15° N and longitude 66–72° E for the period 1995–1998. In the latitude zone 10–15°, maximum TPW is seen 7–12 days prior to the onset of monsoon. Maximum increase in TPW ($\sim 10\text{ kg/m}^2$) is seen in the year 1998 compared to a 3–5 kg/m^2 increase in the years 1995–1997 (Fig. 4), which may be attributed to the El-Nino effect. The TPW is seen to decrease during and after the week of the monsoon onset. We have also analyzed six days of averaged TPW for the 0–5° N and 5–10° N latitude zones, but no significant relations of TPW with the monsoon onset were found.

4 Conclusion

The weekly and monthly variations of TPW over the Arabian Sea and the Indian Ocean are well correlated with onset day of monsoon over the Indian sub-continent. The maximum value of TPW in the 10–15° N latitude zone is seen to appear 7–12 days prior to the monsoon onset at the Kerala coast and so this zone is a key zone for Indian summer monsoon prediction. The analysis of monthly TPW and SST data in the 5–15° N latitude zone indicates the onset month of the monsoon. Further, the analysis of six days averaged data of TPW reveals close relation of TPW with monsoon onset only in the 10–15° N latitude zone. The present results suggest that the launch of microwave sensors with better spatial and temporal coverage may prove to be very useful to predict the onset of the Indian monsoon on the Kerala coast.

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